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Applied Forest Genetics Research and Practical Tree Breeding to Enhance Growth and Yield, Timber Quality and Pest Hardiness in the Peace Region

Alberta
ENVIRONMENTAL PROTECTION

Manning Diversified Forest Products
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MDFP 12 /95
Applied Forest Genetics Research and Practical Tree Breeding to Enhance Growth and Yield, Timber Quality and Pest Hardiness in the Peace Region

1997/98 Update

May 1998

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- Disclaimer -

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Applied Forest Genetics Research and Practical Tree Breeding To Enhance Growth, Yield, Timber Quality and Pest Hardiness Of Future Forests In The Peace Region

Project Progress Report 1997/98
Submitted To
MDFP Research Trust Fund

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May 7, 1998

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1. Introduction

The present report covers the third year of progress for the genetics and tree improvement research and development project in the Manning-Peace River area of the northwest boreal region. Project staff and Prof. Francis Yeh, of the University of Alberta, participated in the Forest Explorers Workshop, which was held in Manning and organized by the Research Trust Fund; the staff and Francis, explained project work and research results. Dr. Rong-Cai Yang left the project to take a research scientist position with Alberta Agriculture, Food and Rural Development. His position was advertised and filled by Dr. Run-Peng Wei who has experience in forest genetics research and a Phd. from the Swedish University of Agricultural Research. Participation in the research component of the Manning Area Woodlot Research and Demonstration project was decided upon and the lodgepole pine operational improvement component for ‘G2’ was finalized for continuation at a scaled back work level.

The current work program, developed and carried out with MDFP Research Trust Fund funding, consisted of: carrying out technical reviews and provision of professional support to industry partners in selection and development of a suitable base population for white spruce and lodgepole pine breeding; professional support for regional progeny test site selection and evaluation; coordination of seed orchard development planning and assistance in experimental design and layout; field measurements and statistical analyses for provenance and progeny research trials located at the Chinchaga experimental site; ongoing cooperation in the exchange of scientific information and genetic stock with the B.C. Ministry of Forests (M.O.F.) beneficial to the ‘G2’ project; new participation in the regional woodlot project. A brief report on the project activities carried out during the year is provided below.

2. Assembly of Breeding Stock and Breeding Plan Development

Industry selection of 70 new regional white spruce parent trees and their initial grafting was completed. Under the reciprocal material exchange agreement with the B.C. M.O.F, 46 B.C. white spruce genetic lines identified as appropriate for Alberta testing have been received, seed archived for progeny testing and grafting completed for establishment of parents in the white spruce clone bank. Five additional selections have been made from better performers in the Chinchaga site white spruce provenance trial (G103G). The base population for Region ‘G2’white spruce now includes 121 parent trees. These are documented in 5 reports, (TIC-96-06, ATISC-97-18, ATISC 98-02, ATISC 98-03 and ATISC 98-06).

As part of the continuing genetic materials and scientific information exchange with B.C M.O.F., a standard set of seedlots for reciprocal testing between Alberta and B.C. was identified. As part of this initiative, a set of white spruce bulk test seedlots has been exchanged. These will be used as controls in the ‘G2’ progeny tests as well as B.C. M.O.F. progeny tests in the Fort St. John and Hudson Hope area. Also, a formal agreement for reciprocal material exchange, scientific information sharing and genetic stock licencing between B.C. and Alberta is in the draft stage.

The conceptual basis for the 'G2' white spruce breeding strategy was reviewed using data collected from regional progeny trials (G133 and G135 series). In light of results, a draft manuscript for a conceptual scientific paper dealing with effective population size and genetic gain versus genetic diversity issues in breeding schemes has been completed and is to be submitted shortly to Silvae Genetica for publication.

3. Lodgepole Pine Improvement

After a review of the project with cooperating partners it was determined that only MDFP and LFS had a continued interest in lodgepole pine tree improvement for the 'G2' area. As this reduced the resources available to continue the project, and additional interim funding could not be found, a meeting was held between MDFP and LFS where a decision was reached to continue the project by scaling back on the number of new regional parent tree selections and reducing the orchard size to 210 ramets.

As part of the LFS continued commitment to the project, John Quinn and Tammy Decosta surveyed wild stands in the Clear Hills area, where there was a regional deficiency, and made 6 additional pine selections. Scions, seed and wood samples were collected and grafting is completed. Seed extracted and seed testing is in progress. This brings the total new regional pine selections to 21 and along with the 40 lodgepole pine genetic lines received under the reciprocal materials exchange agreement with the B.C. M.O.F, the base population for this project now includes 61 parents.

4. Manning Area Woodlot Research and Demonstration Project

John Quinn represented the ATISC at the founding and follow up planning meeting for establishment of the Gurtler Research and Demonstration Woodlot project. He was appointed to represent ATISC on the advisory team where it was decided that ATISC's role would be to advise on project design, provide a portion of the research stock and assist in establishment, assessment and analysis of trials where required.

As part of its commitment to the project, ATISC seeded approximately1,550 research stock in February 1998 for establishment of a species and seed source test and demonstration planting at the Gurtler site. ATISC staff have reviewed proposals and experimental design for the Prairie Farm Rehabilitation (PFRA) hardiness and growth testing trial for shelterbelt species and a stock handling trial to be established and monitored by local high school students. ATISC is also working on the experimental design and planning for an experiment to evaluate various species and sources at the Gurtler site for suitability for establishment of a regional woodlot program.

5. Fairview College Site and Seed Orchards

Delineation of 5 ha was completed by Fairview College along the east boundary of the College property south of Woodmere Nursery (SE 1/4 - SEC 34 - TWP 81 - RGE 3 W6). A shelterbelt of Northwest poplar and lilac was established by ATISC and college staff in early June. Over the course of the summer the Northwest poplar was severely damaged by rodents and was ploughed under by the college in the fall. The Northwest poplar portion of the shelterbelt will be re-established in 1998. The lilac component of the shelterbelt will require some fill in planting. ATISC is supplying the replacement stock.

Orchard water supply options were reviewed by ATISC, Fairview College and GPEC Consulting Ltd. The final decision is to use raw water supplied through an extension of the existing town main supplying Woodmere Nursery. The water will be pumped into an underground cistern located in the northeastern corner of the delineated orchard area to ensure uninterrupted water supply.

Alberta Power was contacted by ATISC to review power supply needs. They have provided an estimate of the cost necessary to run the power supply to the pumphouse. Pumphouse development specs and irrigation needs are currently being reviewed.

Experimental design and field layout plans for the 900 graft white spruce orchard, and area delineation for the pine orchard are completed in readiness for orchard layout and establishment beginning in 2000.

6. Field Trial Measurements and Analyses

The G133 series field trials established at three different sites: HRA (G133A), Chinchaga (G133B), and Red Earth (G133C) were assessed in late September and early October of 1996. Traits measured were 12-year survival, height, vigor, white pine weevil damage and microsite condition. Statistical and genetic analyses were performed for survival, weevil damage and height. Survival and weevil damage were based on plot means while the analysis of height was based on individual tree measurements. A detailed report on the analysis for this trial series is provided in Appendix 1.

The expanded range wide white spruce provenance trial at the Chinchaga River genetics site was assessed at age 7 in the fall of 1997. Assessment included total height, survival and overall tree condition. A detailed report of the analysis for this trial is provided in Appendix 2.

7. New Regional Genetic Test Sites and Chinchaga Experimental Area

Regional genetic test sites have been increased to four from three (site descriptions are provided in Appendix 3). The additional site is a high elevation pine test site located near Sweeney Creek

(Sweeney Creek Genetics Experimental Area) which is to be developed by the LFS. The site has been selected, an ecological survey performed , soil samples analyzed and brush piled for burning. Hines Creek District has submitted a development plan and budget estimate for completion of the site.

A high elevation spruce test site near Clear River (Lund's Landing Genetics Experimental Area) has been selected and is being developed by Canfor, Hines Creek. After a review, the site was expanded, an ecological survey and soil analysis completed, a local bulk seedlot collected and slash cleared. Reservation is pending delineation and mapping of the expanded area.

Due to soil and land ownership concerns, the proposed low elevation test site near MDFP's mill was dropped and a slightly higher elevation site along the Chinchaga Road located (Chinchaga Forestry Road Genetics Experimental Area). ATISC performed a reconnaissance survey of the site in October 1997 and collected soil samples which have been analyzed. Based on results from the soil samples and the reconnaissance survey of the site, this new location appears more suitable for progeny testing than former candidate sites in the area. A second site selected by MDFP for combined pine and spruce progeny testing (Hotchkiss River Genetics Experimental Area) has had an ecological survey performed, analysis of soil pit samples done and clearing and legal survey completed. Mackenzie District has been contacted and application is proceeding for a DRS reservation.

In the early summer of 1997, hand weeding was performed on the Canada range wide white spruce provenance trial (G277) and Region 'H' progeny trial (G157). As clover and grass competition was becoming a serious problem in portions of these young plantations, each experimental tree was located and hand weeded in preparation for assessments in the fall of 1997 and brushing in 1998.

8. Wood Quality Analysis of Superior Trees

Wood collections received by ATISC for the reporting period included samples for 8 pine parent trees. These samples have been analyzed for basic density and fibre length and a summary of results is provided in Appendix 4.

Modifications to the wood fibre length measurement instrumentation and procedures were completed under the direction of Dr. Mathew Koshy, a wood research scientist with the University of British Columbia. The new equipment consists of a computerized image analysis system which has the flexibility for collecting and processing additional information such as fibre width, annual ring counts and early to late wood ratios. Staff training on the new system was carried out in October 1997 and the new system is now operational.

9. 1997/1998 Expenditures

The budget provided by the Research Trust Fund for 1997/98 ($60,000) was fully spent on project activities by March 31, 1998. The project is being delivered through the Contract and Sponsored Research function of the Alberta Tree Improvement and Seed Center *Revolving Fund*. In addition to the Trust funding, a considerable amount of additional resources are being invested by Manning Diversified Forest Products Ltd., Canadian Forest Products Ltd. - Hines Creek and Alberta Land and Forest Service. Additional support is being derived through cooperation with Fairview College and the B.C. Ministry of Forests.

APPENDICES

Appendix 1: Twelve Year Old Genetic Variation of White Spruce Growth and Adaptive Characters in Northwestern Alberta

Appendix 2: Seven Year Old Survival and Height Growth in a Range Wide White Spruce Provenance Trial (G277A)

Appendix 3: Site and Soil Descriptions for Breeding Region "G2"Progeny Test Sites

Appendix 4 : Wood Bulk Density and Fibre Length Analysis

Appendix 1

Twelve Year Old Genetic Variation of White Spruce Growth and Adaptive Characters in Northwestern Alberta

Twelve Year Old Genetic Variation of White Spruce Growth and Adaptive Characters in Northwestern Alberta

1. Introduction

Genetic variation is a prerequisite for successful breeding or conservation programs. For a specific character, the extent of genetic variation is directly proportional to the potential for improvement; the greater the variation, the greater the potential. Genetic variation is also a measure of genetic diversity. Currently, genetic diversity and its conservation are important topics among geneticists and ecologists. Having knowledge of genetic structure and variation, we can plan efficient strategies for species breeding or conservation programs.

White spruce is a widely distributed and important tree species in North America. Genetic variation in this species has, commonly been reported for different regions (Quiring et al. 1991; Hansen 1995, 1996 and references therein; Yang and Dhir 1996; Li et al. 1997; Li et al. 1997). In Alberta, a series of experiments for the purpose of examining this variation was established starting in the 1980's. Genetic variation based on two of these experimental trial series (G132 and G135) was first detailed by Hansen (1995, 1996). The present study reports genetic variation and allocation of variation among regions, stands, families and within families for 12- year height growth and adaptive characters for an additional trial series (G133). The initial aims of G133 were to test and to provide genetic materials for an improvement program in northwestern Alberta.

2. Materials and Methods

The test materials are hierarchically structured, i.e., ecological region–stand–half-sib family. Materials represent 5 different ecological regions including the Dry Mixedwood , Central Mixedwood, Lower Foothills, and Wet Mixedwood Natural Subregions as well as the northeastern Alberta Hart Lake Plain Ecodistrict (2-8 stands from each). From each stand, 4-10 plus trees were selected and open-pollinated seeds were collected. In addition, 2 local bulk seedlots were collected for each of the three test sites. Therefore, in total, the experiment included 125 half-sib families and 6 bulk seedlots..

The three test sites include Hay River (59°08'N, 117°34'W, 370m elevation), Chinchaga River (57°50'N, 118°12'W, 470m elevation), and Red Earth (56°34'N, 115°19'W, 518m elevation), respectively. Three year-old seedlings were out-planted in May 1988. Because of insufficient seedlings for some families, 117 families were included at Hay River, 125 at Chinchaga River and 123 at Red Earth. The experimental design at each site was a randomized complete block with 5 replications, 5-tree row plots and 2.5x2.5m spacing between trees.

The first field assessments were carried out in 1996 to measure the following traits: 11-year height growth, 12-year height, survival, vigor, white pine weevil attack and number of weevil attacks. Trees were scored either 1 (alive) or 0 (dead) for survival, and were scored from 1 to 5 according to increasing growth vigor. Trees were also scored either 1 (present) or 0 (absenct) for white pine weevil attack. The assessments were then edited and a computer data file was established for subsequent statistical analysis and data collection.

Frequency distributions of all plant damage condition codes (poor micro site, insect and disease damage, mechanical injury, etc.) were tabulated to assess their impact on analysis results and interpretations. In general, individuals located on poor microsites were excluded from the analysis.

Variance analysis was carried out to test site (L), block (B(L)), region (R), stand (S(R)), family (F(S)) and their interaction effects: site*region (LR), site*stand (LS(R)), site*family (LF(S)) and block*family (BF(S)), on performance (Y). The population mean was denoted by μ and residuals by e. The multiple linear model for 12-year height and vigor on the basis of individual trees was:

$$Y=\mu+L+B(L)+R+S(R)+F(S)+LR+LS(R)+LF(S)+BF(S)+e$$

and for survival and white pine weevil attack on the basis of plot means, the model was:

$$Y=\mu+L+R+S(R)+F(S)+LR+LS(R)+LF(S)+e$$

For simplicity, all effects were considered random. The error term used for significance tests varied for different effects and traits analyzed (for details see Table 2). Variance components and percentages of total variation were calculated for different effects and traits.

3. Results and Discussion

Population means and standard errors are shown in Table 1 for all half-sib families and local bulk seedlots, respectively, at three sites and over all three sites. The average performance of the whole tested population is a little better than local bulk seedlots at Hay River, but worse than local bulk seedlots at the other two sites and over all three sites. In general, the difference in average performance between exotic and local sources was small. However, large differences exist among regions, stands and families (Table 2 and 3). For example, 12-year height for the top 15 families (including one local seed source) showed height growth was 7.9% to 40.7% greater than the local seed source average.

The results of the ANOVA are compiled in Table 2, and the variance components in Table 3. Region effects on height growth and vigor are significant at $P<0.01$, but the effects on other adaptive traits are not significant. Stand and family have significant effects for all traits at either $P<0.01$ or $P<0.05$ except for vigor. Site*region has significant effects for survival and weevil attack, but not for growth and vigor. Site*stand and site*family have significant effects for all traits at level of $P<0.01$ except for weevil attack. Site and block effects, where applicable, are all significant. Block* family effects are significant for growth and vigor at P=0.0001. It appears from the results that plant vigor is determined more by region of origin and environmental conditions, while other traits have a more complex structure in terms of the allocation of variation.

In general, genetic variation is small, and white spruce performance is mainly influenced by environmental conditions. The within plot, tree-to-tree variation, accounts for most of the total variance, ranging from 75% to 83% for the different traits analyzed. This is followed by between plot variation (block by family within stand interactions) (Table 3). The contributions by region of origin, stand or family are less than 4%. It is more interesting to compare the difference in genetic variation among regions, stands and families. Genetic variation in growth and vigor attributable to region is larger than that attributable to stand and family. In contrast, the family component for survival and white pine weevil attack is greater than for region and stand components. Stand components are intermediate between region and family for all characters studied. It seems that the pattern of genetic structure is different for different adaptive characters in white spruce. The process of adaptation to the same or similar environmental conditions is thus divergent among adaptive characters.

Although region of origin, stand and family may have significant influences on growth or other adaptive performance, significant nonlinear regression was only found for vigor vs longitude and white pine weevil attack vs longitude of stands or families (Figures 1 and 2). The sampled stand and family origins span 3° in latitude, 8°33' in longitude and 579 meters in elevation. As longitude increases, plant vigor decreases and the incidence of white pine weevil attack increases. Results indicate that trees selected in regions and stands from eastern portions of the area have promising vigor and resistance to white pine weevil attack. In an earlier study of white spruce provenances, Yang and Dhir (1996) claimed height and diameter growth was not significantly correlated with any geographic variables. Our study agrees with this conclusion.

Implications from the results of this study for possible breeding and conservation applications include the following: because there are no significant site*region interaction effects on growth and vigor, no further subdivision of the region is necessary if growth and vigor are the main breeding objective. That is, superior genotypes with stable performance over the whole breeding region can be selected and mixed in a single seed orchard. Selection among regions and populations (stands) would have a role in breeding programs, since significant differences are found among regions and populations for height growth and vigor (Table 2). There are favorable relationships between height and vigor ($r=0.658^{**}$) and between height and incidence of weevil attack ($r=-0.227^{ns}$). Therefore, if selection is focused on areas and stands in the eastern portion of the region, fast-growing, vigorous and weevil resistant trees could be expected (Figures 1 and 2). Because of the divergent patterns of genetic structure for different characters (Tables 2 and 3), one possible improvement strategy would be selection among regions and stands aimed at improving height and vigor with selection within regions or stands to increase survival and resistance to weevil attack.

A breeding program often has a clear aim of improving certain traits in a species. Any action taken toward achieving this aim would very likely reduce genetic variation or diversity for characters considered. Other unconsidered traits may be neutral to selection. From a conservation point of view, however, the objective is usually to maintain the whole genetic structure of a species. Therefore, if a program is set up to conserve genetic diversity of white spruce for northwestern Alberta, a reasonable strategy should, according to the results of the present study, consider sampling different levels of genetic variation, i.e. regions, stands, family and within family.

4. Future Work

Follow-up assessments and analysis should be periodically carried out. Diameter and other growing characters should be measured in future work. For breeding purposes, continuous survey could be emphasized on those families originating from regions and stands with low longitude. For conservation purposes, more adaptive characters should be considered in order to plan better conservation programs for the region.

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Yang, R.-C. and Dhir, N.K. 1996. Geographic variation of white spruce provenances at Prairie Creek Genetics Test Site: 18-year results. Alberta Environmental Protection, Land and Forest Service, *Technical Report TIC* 96-10.

Table 1. Population means (standard errors) of 12-year old height (H12, cm), survival (S12, %), vigor (V12), and weevil attack (WPW12, %) at and over three test sites (A, B and C). Trees are scored from 1 to 5 with 1=lowest vigor and 5=highest vigor.

Site		H12	S12	V12	WPW12
A	*	106.3(0.61)	94.6(0.44)	2.77(.010)	19.4(0.79)
	**	102.9(5.20)	90.0(4.80)	2.58(.101)	22.2(7.03)
B	*	124.8(0.82)	93.2(0.49)	3.12(.012)	9.4(0.59)
	**	135.0(5.81)	100.0(0.00)	3.11(.095)	14.0(5.35)
C	*	119.4(0.82)	90.9(0.55)	3.23(.015)	21.8(0.78)
	**	140.1(6.92)	96.0(2.80)	3.50(.119)	16.7(5.44)
Over sites	*	116.9(0.45)	92.8(0.28)	3.05(.008)	17.1(0.43)
	**	120.4(2.20)	94.1(1.17)	3.04(.040)	15.0(1.83)

* Averages over all families nested in 23 stands
** Averages over local bulk seedlots.

Table 2. Significant tests of different effects on 12-year old height (H12), vigor (V12), survival (S12), and white pine weevil attack (WPW12). ANOVA was based on individuals for the first three traits and plot means for the other traits. Test terms (ET) varied for different source effects.

Source		H12	V12			S12	WPW12	
	df	P	P	ET	df	P	P	ET
Site	2	.0005	.0053	2	2	.0268	.0003	6
Block(Site)	12	.0001	.0001	10	-	-	-	
Region	4	.0002	.0086	6	4	.4789	.3465	6
Stand(Region)	18	.0482	.1599	7	18	.0441	.0050	7
Family(Stand)	102	.0015	.1636	9	102	.0352	.0172	8
Site*Region	8	.3163	.3949	10	8	.0042	.0321	10
Site*Stand(Region)	36	.0001	.0004	10	36	.0064	.1468	10
Site*Family(Stand)	190	.0001	.0001	10	190	.0001	.0809	10
Block*Family(Stand)	496	.0001	.0001	10	-	-	-	-
Error	6849				1406			

Table 3. Variance components for 12-year old height (H12), vigor (V12), survival (S12), and white pine weevil attack (WPW12). ANOVA was based on individuals for the first three traits and plot means for the other traits.

Effect	H12	V12	S12	WPW12
Site	5.31	11.04	2.29	9.01
Block(Site)	0.88	4.50	-	-
Region	1.24	0.33	-0.45	-0.42
Stand(Region)	0.31	0.09	1.06	1.89
Family(Stand)	0.18	-0.59	3.63	2.97
Site*Region	-0.35	-0.16	0.86	0.68
Site*Stand(Region)	0.62	0.12	-0.21	0.32
Site*Family(Stand)	4.95	3.03	12.53	2.69
Block*Family(Stand)	10.05	6.82	-	-
Error	76.81	74.83	80.29	82.86
Total	100.00	100.00	100.00	100.00

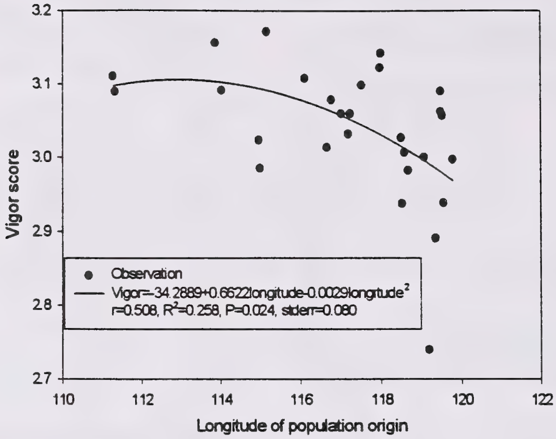

Figure 1. Averaged scores of populations against the longitude of their origins.

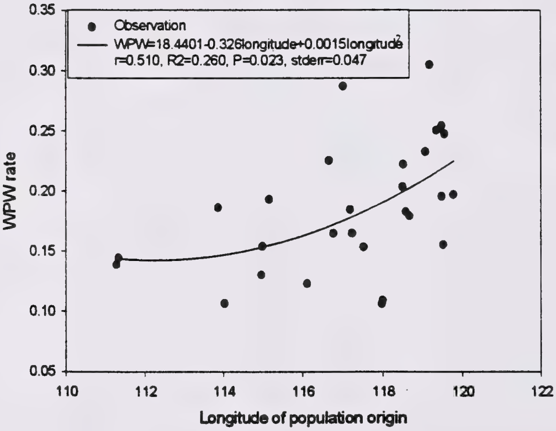

Figure 2. Averaged white pine weevil attack (WPW) rate of populations against the longitude of their origins.

Appendix 2

Seven Year Old Survival and Height Growth in a Range Wide White Spruce Provenance Trial (G277A)

Seven Year Old Survival and Height Growth in a Range Wide White Spruce Provenance Trial (G277A)

1. Introduction

Provenance trials are used to develop knowledge on genetic variation at the population (geographic provenance) level and to provide genetic materials for breeding programs. This can greatly strengthen tree improvement work for a species. A series of province-wide provenance tests of white spruce in Alberta (G103) was initiated in the late 1970's. Subsequently, trials were extended to include Canada-wide provenances (G103RW and G277). G103RW and G277 were out-planted in 1982 and 1993, respectively. Previous studies have shown that variation exists among geographic origins in Alberta (Morgenstern et al 1991; Morgenstern et al 1992; Morgenstern and Keenan 1993; Yang and Dhir 1996). It has also been observed from G103RW, that for early growth and survival, exotic provenances can perform better than Alberta provenances. In G277, provenances from Quebec, Ontario, Manitoba, Saskatchewan, British Columbia, Yukon and Alberta were tested at two sites: Chinchaga (G277A) and Whitecourt (G277B). Some provenances established in G277 are common with G103RW. First assessments were conducted on G277A in 1996. In this document, we report results and conclusions of height growth and survival for 7-year assessment of G277A and compare these results with those for 15-year old measurements of G103RW. Future work requirements for this project are also discussed.

2. Materials and Methods

Bulk seedlots were collected from 40 white spruce wild stands across Canada (Table 1). Among these seed sources, 36 are exotic and 4 are local (note: different origin within Alberta). Plug+3 bareroot seedlings were out-planted at Chinchaga River Genetics Experimental Site (57°49'N, 118°12'W, 500m elevation) in May 1993. Experimental design was randomized complete block with 5 replications, 8-tree row plots and 2.5x2.5m spacing between trees.

First field assessments were carried out in September 1996 to measure the following traits: height growth, survival and individual tree condition. The assessments were then edited and a computer data file was established for subsequent statistical analysis and measurement data input.

Frequency distributions of all plant damage condition codes (poor micro site, insect and disease damage, mechanical injury, etc.) were tabulated to assess the impact on the analysis results and interpretations. In general, individuals located at poor microsites with condition code 'X' were excluded from further analysis.

Variance analysis was carried out to test block, provenance and their interaction effects on height growth, and block and provenance effects on survival. For height growth, block and provenance effects were tested using the interaction as the error term, but the interaction effect was tested against the residual mean square. Analysis for survival was based on plot percentage of surviving individuals, thus giving no interaction effect. Height growth and survival were further regressed against the latitude, longitude and elevation of provenance origin, to detect the patterns of variation in growth and survival along geographic gradients. Either linear or non-linear regression models were employed depending on which one provided the better fit. Finally, provenances that were common with the earlier G103RW experiment at Calling Lake were used to analyze the stability of provenance performance over age.

3. Results and Discussion

3.1. Survival

Variance analysis for G277A shows that at age 7 years, provenance effects are not significant (P=0.40), while block effect is significant (P=0.03). The overall total survival is 77.8%. Mean survival for different provenances ranges from 35.3% to 95.5% (Table 1), and survival for different regions (Alberta, British Columbia, Manitoba, Ontario, Quebec, Saskatchewan and Yukon) ranges from 64.5% to 82.6%. Mean survival for the four Alberta provenances was71.9%, lower than the total survival and the survival of all exotic provenances (78.5%). Provenances from Manitoba, Ontario, and Saskatchewan in general show greater than average survival both overall and in comparison to Alberta provenances. Large differences within regions are also observable (Table 1). As the trial is young, survival trends are not yet well developed and will require monitoring over time to confirm regional patterns.

3.2. Height Growth

The overall mean for height growth±standard error was 69.9±0.69cm. Significant differences were found for all effects: block, P=0.003, provenance, P=0.007 and the interaction, P=.0001. Block, provenance and their interaction effects account for 2.3, 5.8 and 15.6%, respectively, of the total variation, indicating the potential of selecting superior provenances and individuals within provenances for northern Alberta reforestation and breeding programs. The average height of Alberta provenances was 69.7cm(±2.00), almost the same as the overall mean and the average performance (69.9±0.74cm) of the exotic provenances. In general, provenances from Manitoba (72.5±1.55cm) and Ontario (73.0±1.13cm) grew faster than provenances from other regions including Alberta. Large and significant differences within regions are also observable (Table 1).

The four fastest growing provenances are all from Ontario (1340, 1383, 1338 and 1334). The average height of these four best provenances is 83.2cm, 19% taller than the overall mean, and average survival is 81.8%, 5.1% higher than total survival.

3.3. Correlation Between Survival and Height

Survival was plotted against mean height growth for 40 provenances in Figure 1. The relationship is positive but not statistically significant (r=0.235$^{\text{ns}}$, 40 provenances involved), similar to that found for 15-year results of G103RW (r=0.367$^{\text{ns}}$, 23 provenances involved). However, the pattern is important for practical operations, which enables us to select fast-growing seed sources with low mortality either for reforestation or breeding purpose. This is reflected in the four best provenances that perform well in both survival and height growth.

3.4. Geographic Variation

The relationship between the mean performance and origins of 40 provenances were studied using linear correlation analysis and non-linear regression. It shows that both survival and height are negatively related to latitude, longitude and elevation. However, significant correlation was only found for height vs latitude (*r*=-0.383*), height vs longitude (*r*=-0.312*), and survival vs elevation (*r*=-0.587**). Simple linear correlation may not represent the true situations, though. The Gaussian function, suggested by Roberds and Namkoong (1989) to guide population selection along an environmental gradient, was used to fit the performances of provenances against their origins. This function provides better fitting efficiency than linear functions in regression of height vs latitude, height vs longitude, and survival vs altitude (Figure 2a, b and d). Most important is that the Gaussian function disclosed the significant relationship between survival and longitude (Figure 2c) that was not shown in the simple correlation analysis (r=-0.126^{ns}). Nonlinear regressions accounted for 16.5%, 15.5%, 19.6% and 36.2% of variation at the provenance level for height vs latitude, height vs longitude, survival vs longitude and survival vs elevation, respectively.

In general, height growth increases as latitude of origin decreases among the 40 provenances tested. However, the rate of increase clearly drops for latitudes below about 50°. The rate is zero around 46°, suggesting that height growth trend likely reverses for lower latitudes. Based on the results of this early study, it appears that selection of provenances from latitude 42° to 50° could raise the productivity of white spruce in northwestern Alberta (Figure 2a). Maximum predicted response of height occurs around 88° in longitude of origin, indicating that selection of provenances from west Ontario and east Manitoba may also have the potential to increase productivity when moved to northwestern Alberta (Figure 2b). A similar trend was found between survival and longitude (Figure 2c). The maximum predicted survival appears to occur around 97°. Obviously, the range of suitable provenances according to Figure 2c is overlapped with that indicated in Figure 2b, showing again that it is possible to select provenances with high performance in both growth and survival. Survival deceases as elevation of origin increases, and the relationship is close to linear (Figure 2d). Maximum predicted survival occurs around 34m, probably beyond the limit of the natural distribution of white spruce.

Both significant (Figure 2) and non-significant relationships between provenance performance (height and survival) and geographic variables show that exotic provenances may outperform local ones, and the introduction of exotic provenances combined with selection of the outlanders may be an efficient way to raise forest productivity in northwestern Alberta. However, the experiment is too young to extrapolate to a whole forest rotation and thus, decisions on use of exotic superior provenances for reforestation purposes would be premature.

3.5. Relation to an Older Trial

G277A is the extension of an earlier experiment (G103RW) at Calling Lake. Twenty three provenances common in both G277A and G103RW were extracted to compare age-age correlation in mean performances (height and survival) in northern Alberta. Fifteen year old height and survival of G103RW were used (Table 1). The simple correlations are: *r*=0.403^{ns} between 7-yr and 15-yr height, *r*=0.259^{ns} between 7-yr height and 15-year survival, *r*=0.330^{ns} between 7-yr survival and 15-yr height, and *r*=0.223^{ns} between 7-yr and 15-yr survival. Although non-significant, they are all positive. These figures may not represent the genuine situations because two sites were involved, and simple correlation was used. Non-linear functions may provide significant age-age correlations that were not found in linear correlation. Nevertheless, these figures strengthen the possibility of selecting provenances with high performance in both growth and survival.

4. Conclusion Remarks

Significant variation was found among provenances in height. Alberta (local) provenances perform the same as the average of all provenances. Non-significant variation was found among provenances in survival although the trend is for Alberta provenances to exhibit lower survival than the mean for exotics. The four top provenances for growth all originated from Ontario. Top provenances for growth generally have higher than average survival as well. This is also supported by the positive relationship, although non-significant, between height and survival at the same and different ages.

A normal "bell" shape and significant relationship was found for height vs latitude, height vs longitude, survival vs longitude, and survival vs elevation. The nonlinear regressions proved more efficient than linear regression. Optimal provenances seem to be from the southern portion of western Ontario and eastern Manitoba. Normally, high survival is correlated with low elevation of provenance origin.

Because the experiment is young, it is too early to draw conclusions and decide upon selection and extension of superior provenances to northwestern Alberta for reforestation purposes. Valuable information will be accumulated in consecutive assessments over time and more extensive testing of the best provenances will be considered.

5. Future Work Needs

Maintain the experiment by removing competition and improving the soil conditions. Follow-up assessments will be carried out in year 2000 and thereafter every 5 years. More adaptive characters will be considered in order to better outline adaptiveness of exotic provenances for northwestern. A technical report summarizing early results and conclusions of white spruce provenance variations will be written using 10-year old assessments. A preliminary screening of superior provenances for testing in northwestern Alberta may also be in order.

6. References

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Morgenstern, E.K. and Keenan, T.J. 1993. Analysis of white spruce provenance experiment: Implications for the revision of seed zones. *Unpublished Contract Report* (Alberta Land and Forest Service), Part 1, 19p, and Part 3, 31p.

Morgenstern, E.K., Keenan, T.J., and Mullin, T.J. 1992. Analysis of white spruce provenance experiment: Implications for the revision of seed zones. *Unpublished Contract Report* (Alberta Land and Forest Service), Part 2, 26p.

Table 1. Origins, mean height (H), standard error (SE), and survival (S) at 7-year old of 40 white spruce provenances tested at Chinchaga (Lat 57°49'N, Long 118°12', Elev 500m). Mean height (H*) and survival (S*) at 15-year old of some common provenances tested at Calling Lake (Lat 57°17'N, Long 113°09', Elev (625m) are listed in the last two columns.

Accession Number	Natural location	Lat	Long	Elev(m)	G277A			G103RW	
					H(cm)	SE(cm)	S(%)	H*(cm)	S(%)
		Exotic Seedlots							
1327	Quebec Dasserat Twp.	48°13'	79°29'	289	60.7	3.1	80.0	309.0	96
1329	Quebec Cimon Twp.	48°17'	71°00'	198	67.8	4.3	67.5	285.9	76
1330	Quebec McGill Twp.	46°15'	75°35'	304	62.7	3.0	78.9	265.6	76
1331	Quebec Laurentides Twp.	47°30'	71°00'	792	79.2	12.8	35.3	254.2	88
1333	Ontario Havelock	44°26'	77°50'	180	73.7	4.3	92.3	260.3	96
1334	Ontario Forresters Fall	45°41'	76°48'	137	81.9	5.4	87.5	274.1	84
1335	Ontario Burt. Twp.	48°02'	80°22'	300	60.8	4.2	84.0	286.9	84
1336	Ontario Waweig Lake	50°09'	89°07'	305	71.3	3.5	92.6		
1337	Ontario Caramat	49°36'	89°09'	305	82.5	4.0	67.7	259.4	88
1338	Ontario Twist Lake	49°22'	89°45'	425	65.0	4.2	64.3	255.6	64
1340	Ontario Kenora	49°45'	94°36'	365	84.9	6.0	91.7		
1341	Ontario Dryden	49°42'	93°30'	396	75.8	2.7	91.3		
1344	Ontario Red Lake	51°02'	93°48'	365	74.1	3.7	80.6		
1346	Ontario Timmins Twp.	48°18'	80°45'	305	68.0	4.0	70.6		
1350	Ontario Kapuskasing	49°18'	82°42'	900	68.6	4.5	69.0	297.9	88
1351	Manitoba Lake St. George	51°43'	96°25'	243	65.2	4.6	76.9	290.1	84
1352	Manitoba Angle Inlet	49°19'	95°20'	335	74.4	4.1	78.6	331.7	88
1353	Manitoba West Kawk Lake	49°47'	95°15'	335	75.1	5.4	78.6		
1354	Manitoba Bernic Lake	50°25'	95°36'	274	75.1	3.6	95.5		
1355	Manitoba Minago River	54°10'	99°10'	243	54.3	4.6	81.3	221.4	84
1356	Manitoba East Braintree	49°42'	95°35'	335	72.9	2.9	77.1		
1357	Manitoba Cold Creek	51°04'	95°47'	304	78.0	3.4	83.9	307.2	100
1358	Manitoba Mid-Interlake	52°12'	98°47'	274	75.6	5.2	88.9		
1360	Saskatchewan Candle L.	53°55'	104°50'	502	70.2	3.4	80.0		
1361	Saskatchewan Candle L.	53°45'	105°12'	494	74.6	4.1	92.3	289.5	92
1362	Saskatchewan Besnard L.	55°19'	106°05'	401	59.4	4.0	72.4	273.8	96
1363	Saskatchewan Old Ch. R.	53°55'	102°23'	266	57.9	3.6	80.0	267.6	88
1366	Saskatchewan Dore Lake	54°42'	107°16'	485	70.5	4.4	75.9		
1374	British Columbia G.B.C.	56°30'	122°10'	823	62.6	4.5	64.5	231.1	88
1378	Ontario P.F.E.S.	45°59'	77°27'	160	65.5	3.5	74.2	298.0	76
1379	Ontario Rankin	45°45'	77°10'	152	63.3	4.3	81.5		
1381	Yukon Whitehorse	60°41'	135°08'	762	52.5	3.8	65.7	169.0	76
1382	Ontario Davis Mills	45°45'	77°12'	152	77.1	4.1	85.0		
1383	Ontario Douglas	45°30'	77°01'	121	83.5	5.2	83.9	287.4	84
1384	Ontario Forresters Falls	45°41'	76°48'	140	67.4	4.2	86.7	271.9	72
1387	Yukon Carmacks	62°03'	136°14'	533	63.2	3.7	67.9	147.8	76
		Local Seedlots							
2	Footner Lake	58°44'	117°15'	335	70.1	4.2	88.9		
21	Footner Lake	57°36'	117°31'	460	75.1	3.5	73.7		
23	Peace River	56°34'	119°40'	762	66.7	5.5	75.0		
2409	Peace River	56°03'	118°05'	609	64.5	3.1	56.4		
Overall mean					69.9	0.7	77.8	266.8	84.5

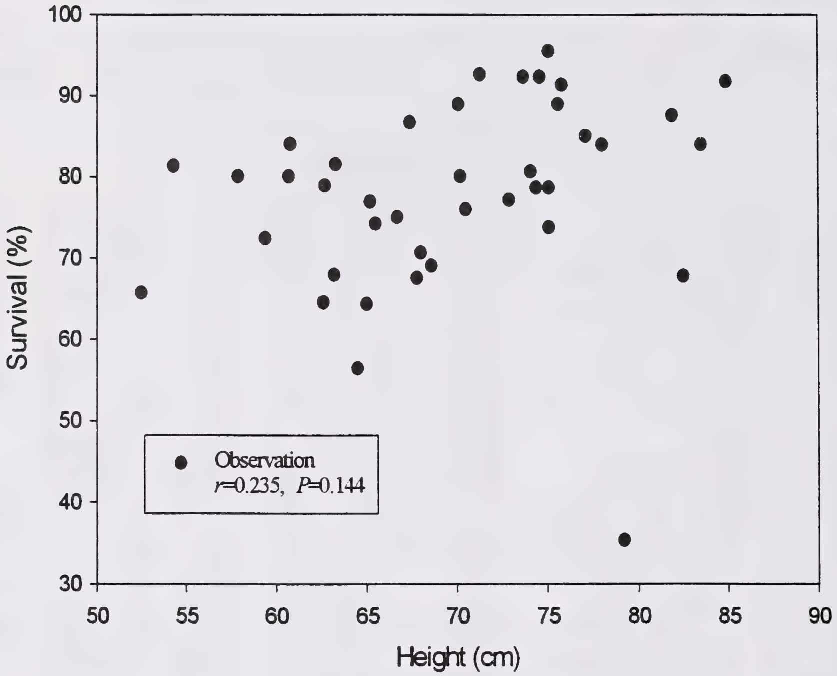

Figure 1. Plot of survival against height at 7-year old for 40 provenances. Positive but non-significant correlation was found between survival and height.

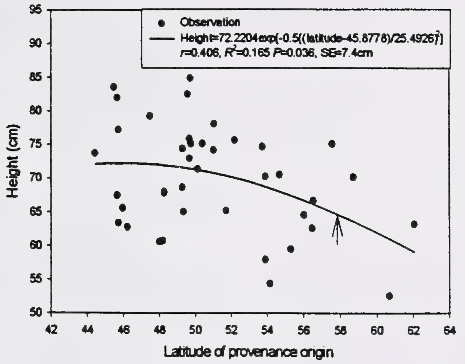

Figure 2a. Observation and regression of 7-year old height against the latitudes of 40 provenances' origins. The upward arrow indicates the test site.

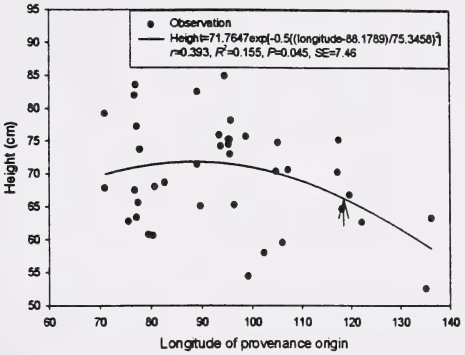

Figure 2b. Observation and regression of 7-year old height against the longitudes of 40 provenances' origins. The upward arrow indicates the test site.

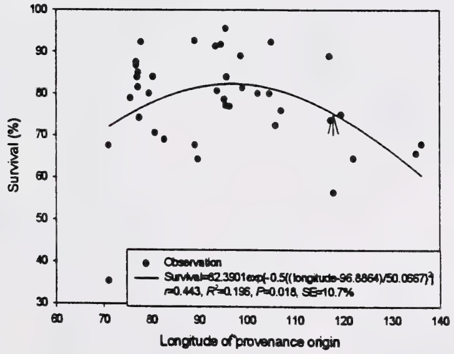

Figure 2c. Observation and regression of 7-year old survival against the longitude of 40 provenances' origins. The upward arrow indicates the test site.

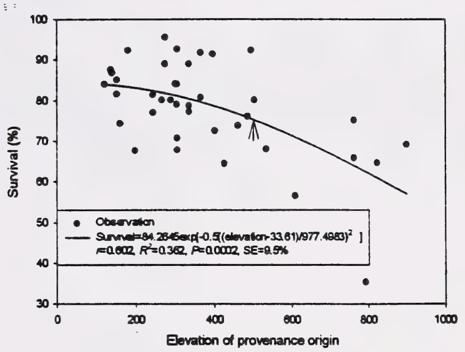

Figure 2d. Observation and regression of 7-year old survival against the elevation of 40 provenances' origins. The upward arrow indicates the test site.

APPENDIX 3

Site and Soil Descriptions for Breeding Region "G2" Progeny Test Sites

1. Chinchaga Forestry Road Genetics Experimental Area

A. Site Description

Location:

Latitude: 57° 03'
Longitude: 117° 38'
Elevation: 530 m
Legal: NW 33-93-23-W5

Site:

Aspect: East
Slope: 0% to 2%
Topography: Level to Undulating
Parent Material: Lacustro- Till
Soil Classification: Humic Luvic Gleysol (indications of periodic saturation and groundwater discharge)
Stand: A2SwPb/B1AwPbSw
Moisture Regime: Mesic to Subhygric
Nutrient Regime: Rich (except for Nitrogen) and alkaline
Ecosite: BM Sw/low-bush cranberry to Pb-Aw/dogwood/fern (transitional D3.3 to E1.1)

Vegetation:

Main Canopy: white spruce & balsam poplar
Secondary Canopy: trembling aspen, balsam poplar & white spruce
Tall Shrub: willow & white spruce
Shrub: white spruce, willow, buffalo berry, red-osier dogwood, buck brush, prickly rose, bracted honeysuckle & low bush cranberry
Herb: showy aster, marsh-reed grass, fireweed, twinflower, and cream-colored vetchling (frost and light snow cover at time of survey)
Moss: not surveyed due to light snow cover

Predicted Climate:

Mean Annual Temp: -0.3°C
Mean Summer Temp: 14.3°C
Mean Annual Precipitation: 442 mm
Mean Summer Precip: 199 mm
FFP: 96 days
GDD >5°C: 1226 days

B. Soil Pit Description

cm	Horizon	Description
7-0	LH	mull-like moder
0-28	Ah	very dark grey (10YR 3/1); sandy loam; strong fine to medium granular; clear irregular boundary; very friable, neutral reaction; stoneless.
28-47	Aejgj	light gray (10YR 7/1) in gray matrix (10YR 5/1); silty clay; weak coarse sub-angular blocky breaking to strong fine to medium granular; clear wavy boundary; friable; moderately alkaline; stoneless.
47-65	Btjg	light gray (10YR 7/1) in gray matrix (10YR 5/1); silty clay; fine weak prismatic breaking to moderate fine to medium sub-angular blocky; gradual smooth boundary; firm; common fine faint (10YR 5/3) mottles; moderately alkaline; stoneless.
65-80	Cg	light gray (10YR 7/1) in gray matrix (10YR 6/1); silty clay; weak coarse, sub-angular blocky breaking to moderate, fine sub-angular blocky; gradual smooth boundary; firm; moderately alkaline; stoneless with sand lenses.
80-110	Cgj	gray (10YR 5/2); clay; massive; few fine distinct (10YR 5/5) mottles in sand lenses; moderately alkaline;

C. Soil Pit Chemical and Physical Properties

Horizon	Depth (cm)	Particle Size %			pH	CEC meq/ 100g	Org C %	Organic Matter %	Micro Nutrients ug/g						
		S	Si	C					N	P	K	Ca	Mg	Na	S
Ah	0-28	59	31	10	6.6	31.5	5.7	11.4	1.4	16.4	14.4	264	66.6		63.1
Aejgj	28-47	4	51	45	8.2	30.0	0.1	1.6	0.1	9.7	12.5	59.2	15.8		36.4
Btjg	47-65	0	55	45	8.4	21.8	0.8	1.7	0.2	8.6	60.1	84.0	43.3		82.2
Cg	65-80	11	44	45	8.4									422	
Cgj	80-110	5	38	57	8.2									440	

2. Hotchkiss River Genetics Experimental Area

A. Site Description

Location:

Latitude:	57° 08'
Longitude:	118° 25'
Elevation:	750 m
Legal:	NE & SE 33-94-3-W6 and SW and NW 34-94-3-W6

Site:

Aspect:	East North East
Slope:	2% to 5%
Topography:	Sloping
Parent Material:	Fine Textured Till
Soil Classification:	Brunisolic Gray Luvisol
Stand:	C2 - C3 PlAw
Soil Drainage:	Mesic
Nutrient Regime:	Mesic
Ecosite:	LF Aw- Sw- Pl/ green alder/ hairy wild rye (C3.2)

Vegetation:

Main Canopy:	lodgepole pine, trembling aspen
Secondary Canopy:	nil
Tall Shrub:	green alder, willow
Shrub:	low bush cranberry, bunch berry, prickly rose, small-bog cranberry, Labrador tea & buffalo berry
Herb:	fireweed, twinflower, palmate-leaved coltsfoot, hairy wild rye, stiff club-moss, common pink wintergreen, wild lilly-of-the-valley, dewberry, cream-colored vetchling , meadow horsetail
Moss:	Schreber's moss, stair-step moss, knight's plume moss (continuous moss cover)

Predicted Climate:

Mean Annual Temp. :	-1.4°C
Mean Summer Temp.	13.5°C
Mean Annual Precipitation:	497 mm
Mean Summer Precipitation:	224 mm
FFP:	98 days
GDD >5°C:	899 days

B. Soil Pit Description

cm	Horizon	Description
7-0	LFH	fibrimor
0-15	Ae	light gray (10YR 7/2) (some dark staining); loam; medium coarse platy; gradual irregular boundary; very friable, very strongly acid; 1%-2% fine gravel.
10-15	Bm	pale brown (10YR 6/3) with areas of light brown (7.5YR 6/3); clay loam; weak medium platy; discontinuous horizon with clear wavy boundary; friable; very strongly acid; 1%-2% fine to medium gravel.
15-40	Bt	very pale brown (10YR 7/3); silty clay; moderate, coarse to medium, subangular blocky breaking to strong, fine, subangular blocky ; clear smooth boundary; firm; common fine faint (10YR 5/4) mottles; strongly acid; 2%-5% medium gravel;
40-75	BC	light yellowish brown (10YR 6/4); silty clay loam; strong, fine, sub-angular blocky; gradual smooth boundary; firm; medium acid; 1%-2% gravel.
75-100	C	light brownish gray (10YR 6/2); clay loam; massive; firm; neutral; stoneless;

C. Soil Pit Chemical and Physical Properties

Horizon	Depth (cm)	Particle Size %			pH	CEC meq/ 100g	Org. C %	Organic Matter %	Micro Nutrients ug/g						
		S	Si	C					N	P	K	Ca	Mg	Na	S
Ae	0-15	29	46	25	4.9	9.8	0.6	2.9	3.4	0.2	8.6	14.7	4.8	7.21	13.0
Bm	10-15	22	45	33	4.8	16.8	0.7	3.5	5.3	0.2	11.9	18.2	7.1	12.4	18.3
Bt	15-40	18	41	41	5.1	18.5	0.4	3.4	6.9	0.2	6.1	7.9	4.4	16.7	19.2
BC	40-75	18	42	40	5.9	-	-	-	-	-	-	-	-	-	-
C	75-100	21	40	39	7.1	-	-	-	-	-	-	-	-	-	-

3. Sweeney Creek Genetics Experimental Area

A. Site Description

Location:

Latitude:	56° 33'
Longitude:	119° 49'
Elevation:	920 m
Legal:	NW & NE 3-88-12-W6

Site:

Aspect:	North
Slope:	3% to 7%
Topography:	Sloping
Parent Material:	Fine Textured Till
Soil Classification:	Eluviated Dystric Brunisol
Soil Drainage:	Moderately Well
Stand:	C3 SwPlAw/Sw (Bw)
Site Type:	white spruce / bracted honeysuckle (transitional Lower to Upper Foothills)

Vegetation:

Main Canopy:	white spruce, trembling aspen & lodgepole pine
Secondary Canopy:	white spruce and paper birch
Tall Shrub:	willow, white spruce and subalpine fir
Shrub:	wild red raspberry, bracted honeysuckle, low-bush cranberry, river alder, prickly rose and bristly black currant.
Herb:	tall lungwort, Lindley's aster, red baneberry, palmate-leaved coltsfoot, cream-coloured vetchling, five-leaved bramble, twisted stalk, marsh-reed grass, woodland horsetail, heart-leaved arnica, twinflower, bunchberry, wild lily-of-the-valley, sweet-scented bedstraw, fireweed, cow parsnip, and lady fern.
Moss:	Schreber's moss, stair-step moss, knight's plume moss

Vegetation indicates periodic seepage and enrichment

Predicted Climate:

Mean Annual Temp:	-1.6°C
Mean JJA Temp:	13.2°C
Mean Annual Precip:	553 mm
Mean JJA Precip:	239 mm
FFP:	95 days
GDD >5°C:	600 days

B. Soil Description

cm	Horizon	Description
5-0	LH	fibrimor
0-7	Ahe	gray (10YR 5/1); loam; weak, medium,granular; gradual irregular boundary; friable, very strongly acid; 1%-2% fine gravel.
7-15	Ae	light gray (10YR 7/2); loam; weak, medium, platy breaking to weak, medium, granular; clear wavy boundary; firm; extremely acid; 1%-2% fine gravel.
15-30	Btj	very pale brown (10YR 7/3); loam, coarse, subangular blocky breaking to weak, medium, granular; clear smooth boundary; firm; few, fine faint (10YR 7/4) mottles; very strongly acid; 2%-5% fine gravel;
30-65	BC	pale brown (10YR 6/3); silty clay-loam; weak, medium, subangular blocky breaking to moderate, medium, granular; gradual, smooth boundary; firm; common, medium, distinct (10YR 6/6) mottles; extremely acid; 3%-7% fine gravel.
65-100	C	light brownish gray (10YR 6/2); sandy loam; massive; very firm; common, fine, distinct (10YR 6/6) mottles; strongly acid; 2% to 5% fine gravel.

C. Soil Chemical and Physical Properties

Horizon	Depth (cm)	Particle Size %			pH	CEC meq/ 100g	Org. C %	Organic Matter %	Micro Nutrients ug/g						
		S	Si	C					N	P	K	Ca	Mg	Na	S
Ahe	0-7	31	47	22	5.0	14.4	1.0	2.0	2.5	4.4	22.3	49.5	13.9	-	11.9
Ae	17-15	35	45	20	4.2	17.5	0.6	1.2	2.3	2.5	18.8	26.2	10.4	-	7.8
Btj	15-30	32	46	23	4.6	21.0	0.5	1.0	3.1	3.0	21.5	40.4	14.7	-	1.0
BC	30-65	15	49	36	4.1	-	-	-	-	-	-	-	-	17.8	-
C	65-100	59	24	17	5.4	-	-	-	-	-	-	-	-	49.0	-

4. Lund's Landing Genetics Experimental Area

A. Site Description

Location:

Latitude: 56° 34'
Longitude: 119° 52'
Elevation: 915 m
Legal: NW 8-88-12-W6

Site:

Aspect: East Northeast
Slope: 3% to 7%
Topography: Crest
Parent Material: Fine Textured Till
Soil Classification: Gleyed Eluviated Dystric Brunisol
Stand: C3 Pl (AwBw)
Moisture Regime: Mesic to Subhygric (lateral seepage through mid to lower solum)
Nutrient Regime: Mesic (good nitrogen but low on other micronutrients) extremely acid
Ecosite: UF ; Pl/green alder/ feathermoss to Aw-Sw-Pl /green alder/feather moss (E 1.1 to E2.1)

Vegetation:

Main Canopy: lodgpole pine and trembling aspen
Secondary Canopy: paper birch
Tall Shrub: river alder and mountain ash
Shrub: low-bush cranberry, prickly rose, bracted honeysuckle, prickly black currant, wild red raspberry, Labrador tea, blueberry, subalpine fir, white spruce and black spruce.
Herb: five-leaved bramble (almost continuous cover), bunchberry, twinflower, fireweed, meadow horsetail, stiff club-moss, marsh reed grass, twisted stalk and lady fern.
Moss: Schreber's moss and stair-step moss.

Predicted Climate:

Mean Annual Temp: -1.6°C
Mean Summer Temp: 13.2°C
Mean Annual Precipitation: 553 mm
Mean Summer Precipitation: 238 mm
FFP: 95 days
GDD >5°C: 600 days

B. Soil Pit Description

cm	Horizon	Description
7-0	LH	fibrimor
0-10	Ae	light gray (10YR 7/1); loam; weak, medium, platy; clear, smooth boundary; very friable, few fine faint (10YR 7/3) mottles, extremely acid; 1%-2% fine gravel.
10-22	Bm	light yellowish brown (10YR 6/4); clay loam; strong, fine, sub-angular blocky; clear smooth boundary; friable; extremely acid; 2%-5% fine gravel.
22-35	Btj	pale brown (10YR 6/3); clay loam; moderate, medium, subangular blocky breaking to strong, fine, sub-angular blocky; gradual smooth boundary; firm; few, fine faint (10YR 6/4) mottles; extremely acid; 5%-10% fine gravel;
35-60	BCgj	pale brown (10YR 6/3); clay-loam; moderate, medium, prismatic breaking to weak, medium, sub-angular blocky; gradual smooth boundary; firm; common, medium, distinct (10YR 6/6) mottles; extremely acid; 5%-10% fine gravel.
60-100	Cgj	light brownish gray (10YR 6/2); clay loam; massive; firm; common, medium, distinct (10YR 6/6) mottles; extremely acid; 2% to 5% fine gravel.

C. Soil Pit Chemical and Physical Properties

Horizon	Depth (cm)	Particle Size %			pH	CEC meq/ 100g	Org. C %	Organic Matter %	Micro Nutrients ug/g						
		S	Si	C					N	P	K	Ca	Mg	Na	S
Ae	0-7	37	42	21	4.3	8.2	0.4	2.6	4.1	0.2	6.9	4.6	2.4	11.2	10.0
Bm	17-15	28	40	32	4.0	14.4	0.5	3.6	5.9	0.2	5.1	7.0	2.0	0.6	23.7
Btj	15-30	34	34	32	4.0	16.4	0.5	3.6	6.3	0.2	4.9	5.9	1.7	2.9	19.6
BCgj	30-65	28	40	32	4.1	-	-	-	-	-	-	-	-	-	-
Cgj	65-100	24	39	37	4.1	-	-	-	-	-	-	-	-	-	-

Appendix 4

Wood Bulk Density and Fibre Length Analysis

Table 1. Wood Density Analysis Results for Eight Lodgepole Pine Parent Trees Selected in Breeding Region G2

FIELD NO.	ORTET NO.	DATE REC'D	DBH RINGS	MEAN WOOD DENSITY JUVENILE*	INTERMEDIATE**	MATURE***	WEIGHTED MEAN
P1D-01-97 Pl	X1572	97-11-27	97	0.3973	0.4146	0.4008	0.4043
P1D-02-97 Pl	X1573	97-11-27	96	0.4117	0.4588	0.3933	0.4180
P1D-03-97 Pl	X1574	97-11-27	98	0.3493	0.4031	0.4235	0.4053
P1D-04-97 Pl	X1575	97-11-27	109	0.4259	0.4289	0.4442	0.4391
P2D-05-97 Pl	X1576	97-11-27	96	0.3778	0.4224	0.4046	0.4069
P1D-06-97 Pl	X1577	97-11-27	94	0.3404	0.3872	0.3634	0.3676
P6-01-97 Pl	X1533	97-02-21	61	0.3572	0.4099	0.4380	0.3973
P10-01-97 Pl	X1532	97-02-21	57	0.3646	0.3870	0.3603	0.3755
SUMMARY			MEAN	0.3780	0.4140	0.4035	0.4018
			N	8	8	8	8
			STD	0.0308	0.0236	0.0312	0.0226
			CV (%)	8.1548	5.6890	7.7431	5.6289

* Juvenile measurements were done on wood taken from 0-20 year rings.

** Intermediate measurements were done on wood taken from 21-50 year rings.

*** Mature measurements were done on wood taken from 51+ year rings.

Table 2. Wood Fibre Length Analysis Results for Eight Lodgepole Pine Parent Trees Selected in Breeding Region G2

FIELD NO.	ORTET NO.	DATE REC'D	DBH RINGS	MEAN WOOD FIBRE LENGTH (mm) JUVENILE*	INTERMEDIATE**	MATURE***	WEIGHTED MEAN (mm)
P1D-01-97 Pl	X1572	97-11-27	97	2.0523	2.9849	2.7183	2.7286
P1D-02-97 Pl	X1573	97-11-27	96	2.2363	3.0323	3.4165	3.1136
P1D-03-97 Pl	X1574	97-11-27	98	2.6148	3.3500	3.5217	3.3223
P1D-04-97 Pl	X1575	97-11-27	109	2.4841	2.8853	3.3957	3.1995
P2D-05-97 Pl	X1576	97-11-27	96	2.0813	2.4525	2.6835	2.5056
P1D-06-97 Pl	X1577	97-11-27	94	2.5341	3.1293	3.3688	3.1781
P6-02-97 Pl	X1533	97-02-21	61	3.1096	3.7756	4.2223	3.6344
P10-01-97 Pl	X1532	97-02-21	57	2.7328	3.3398	3.6193	3.1683
SUMMARY			MEAN	2.4807	3.1187	3.3683	3.1063
			N	8	8	8	8
			STD	0.3551	0.3887	0.4943	0.3478
			CV (%)	14.3149	12.4639	14.6754	11.1968

* Juvenile measurements were done on wood taken from 17-20 year rings.

** Intermediate measurements were done on wood taken from 47-50 year rings.

*** Mature measurements were done on wood taken from 77-80 year rings.

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